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Enhancing storage permittivity by incorporating PDMS-PEG multi block copolymers in binary polymer blends

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Publication date:
2015

Document Version
Peer reviewed version

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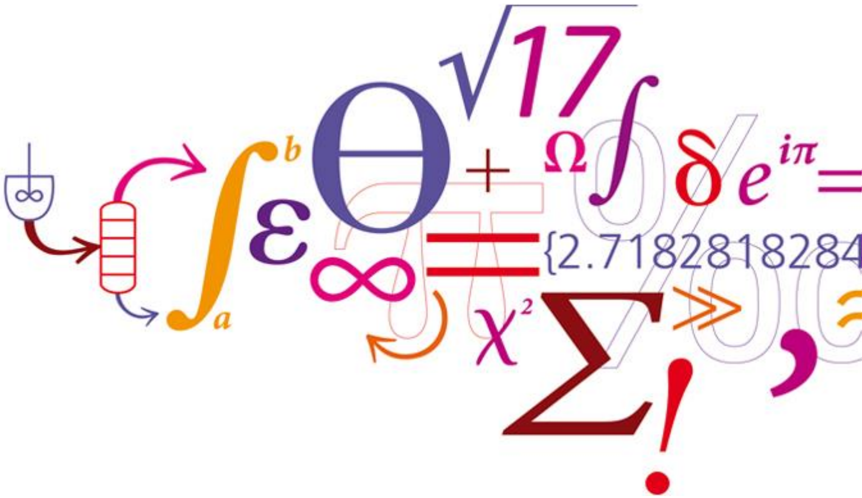
Nordic Polymer Days 2015

IDA Copenhagen



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Danish Polymer Centre (DPC)

DTU Chemical Engineering

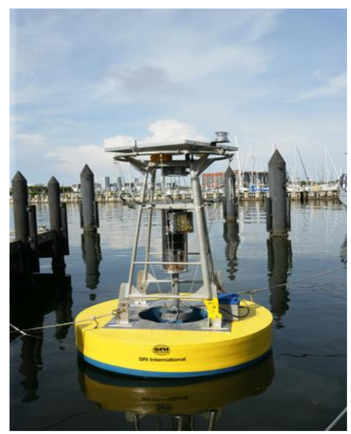
Department of Chemical and Biochemical Engineering

Background of dielectric elastomer (DE)

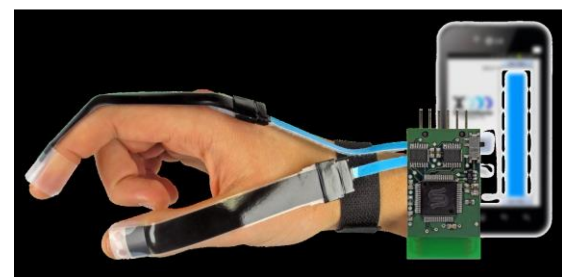
DE - changes size/shape (presence of electrical field)
- compliant capacitor (electrostatic stress > elastic stress)

DEs: silicones, acrylates, polyurethanes and thermoplastic elastomer copolymer.

Actuator
Herbert Shea – EPFL Switzerland

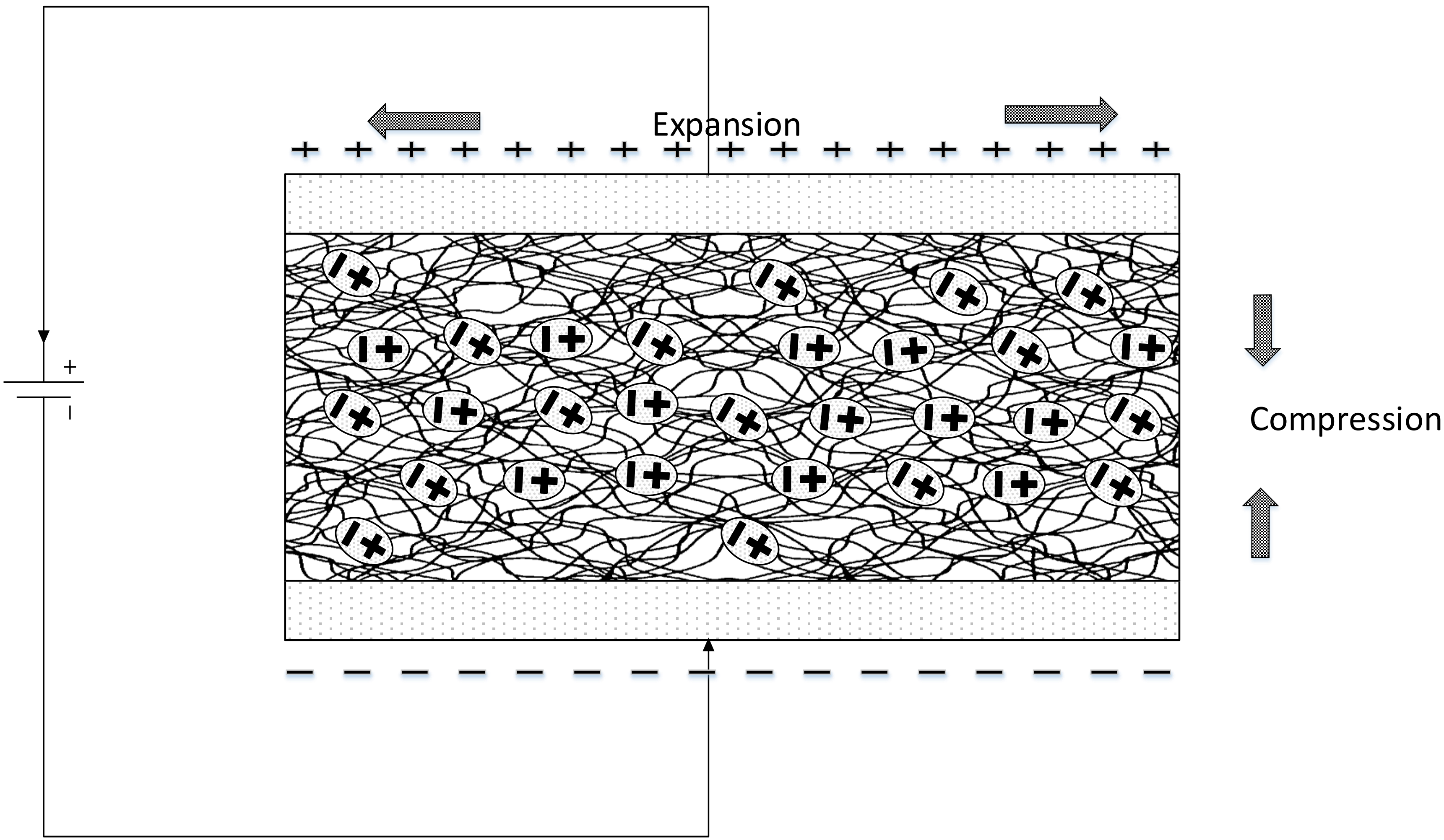


Generator
Roy Kornbluh et al - SRI International, USA



Sensor
Ben O'Brien – University of Auckland

DE as an actuator



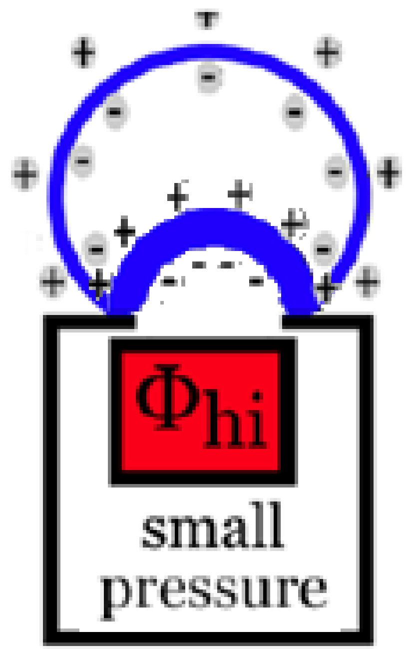
DE as a generator

High mechanical potential
Low electrical potential

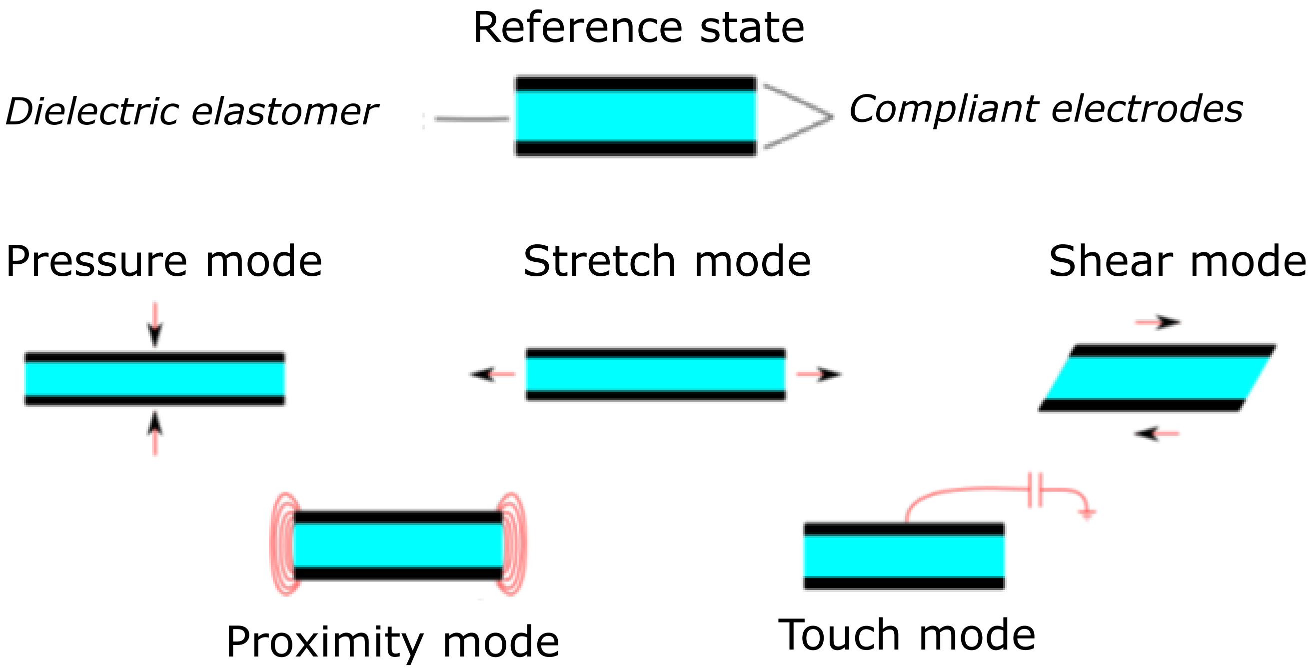
→

Low mechanical potential
High electrical potential

Deflation



DE as a sensor



Proximity

$$C = \varepsilon_0 \varepsilon_r \frac{A}{t} + C_{parasitic}$$

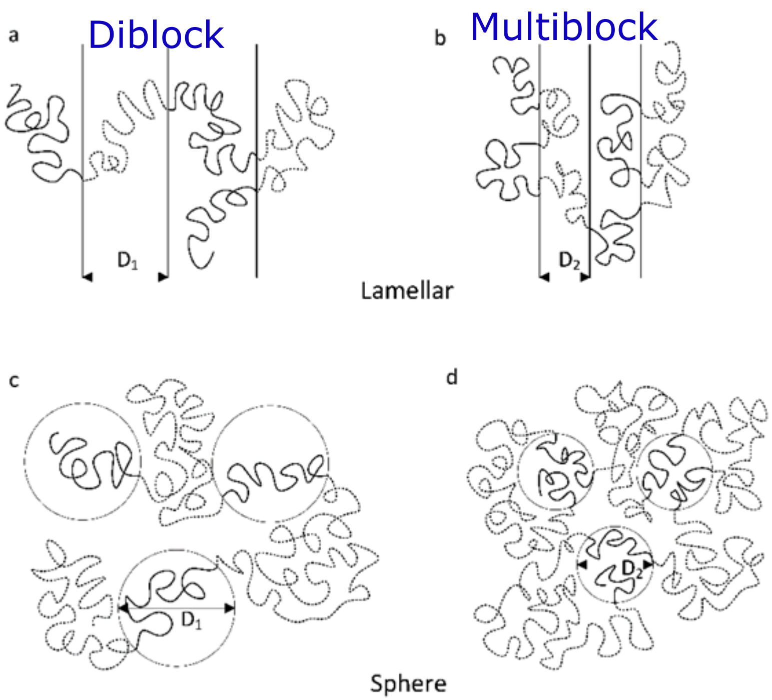
Touch

Pressure,
stretch & shear

Morphology in block copolymers

Multiblock copolymer

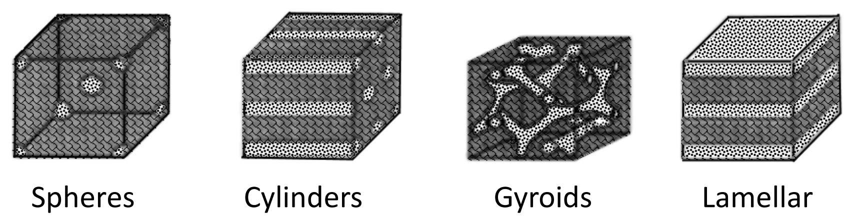
(AB)$_n$



Domain spacings [3]

Morphology - COMPLEX

Common morphologies of block copolymers

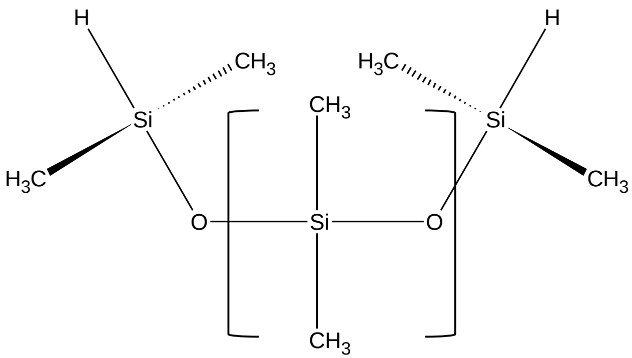


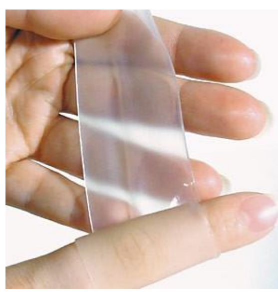
Increasing volume fraction (f_A) [1]

[1] Bates, F. S., & Fredrickson, G. H. (1999). Block Copolymers—Designer Soft Materials. *Physics Today*, *52*(2), 32.
[2] *Y. Mai and A. Eisenberg, Chem. Soc. Rev., 2012, 41, 5969-5985.*
[3] Y. Matsushita, Y. Mogit, H. Mukai and J. Watanabe, *Polym. J.*, 1994, **35**, 246–249.

PDMS versus PEG

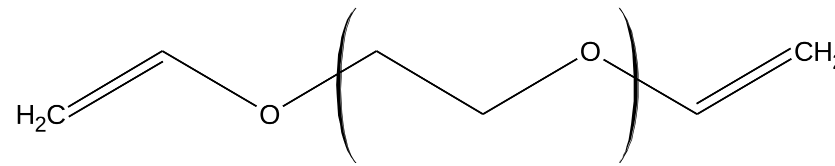
Polydimethylsiloxane (PDMS)

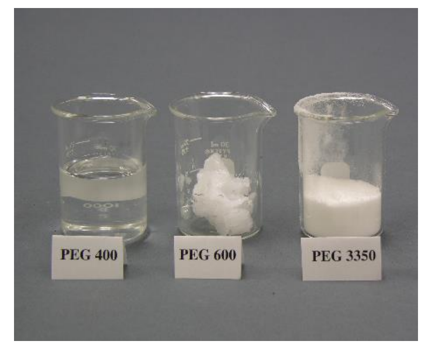




- Low modulus
- Low conductivity
- Low permittivity (net dipole moment, μ=0.6 – 0.9 D)[4]

Polyethyleneglycol (PEG)





- High Permittivity (a dipole moment, μ=3.91 D[5])
- High conductivity
- Not flexible

4 J. N. Lee, C. Park and G. M. Whitesides, *Anal. Chem.*, 2003, **75**, 6544–6554.
5 R. J. Sengwa, K. Kaur and R. Chaudhary, *Polym. Int.*, 2000, **608**, 599–608.

Experimental

Sample details for PDMS-PEG multiblock copolymers

PDMS-PEG block copolymer	Number average molecular weight of H-PDMS ($M_{n,PDMS}$) [g/mol]	Number of repeating units in PDMS (m)	Theoretical number of repeating units in $(\text{PDMS-PEG})_X$ (X)	Stoichiometric ratio (r_1)	Volume fraction of PDMS (f_A)
PDMS81-PEG	6000.00	81	5	1.21	0.94
PDMS14-PEG	1050.00	14	23	1.04	0.75
PDMS7-PEG	550.00	7	37	1.03	0.62
PDMS3-PEG	208.00	3	56	1.02	0.45

Note: M_n of PEG in PDMS-PEG block copolymer is 250 g/mol

The blends and sample preparation

1

Synthesis PDMS-PEG prepolymer

2

1) Crosslink PDMS-PEG block copolymer (BCP) with 9-functional (9-f) crosslinker

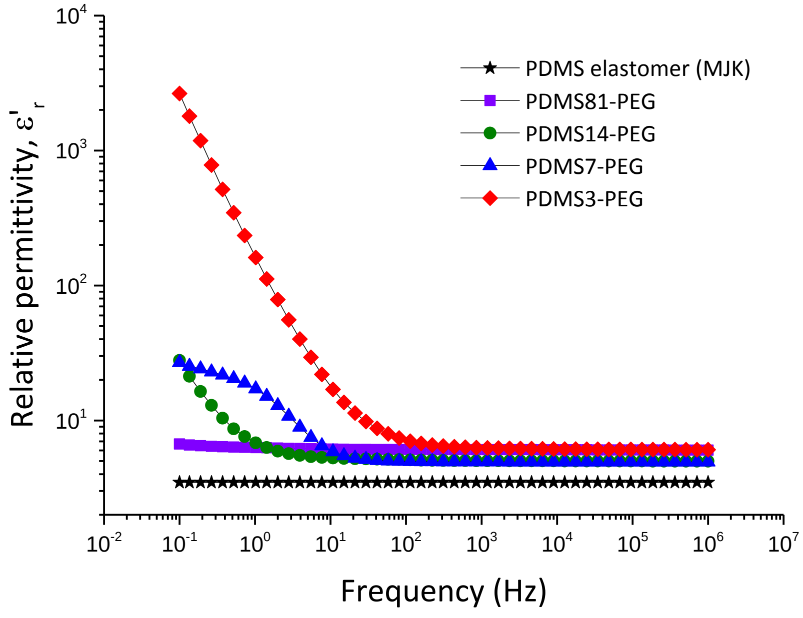
2) Blend the block copolymer with commercial PDMS (MJK) and crosslink with 9-f crosslinker

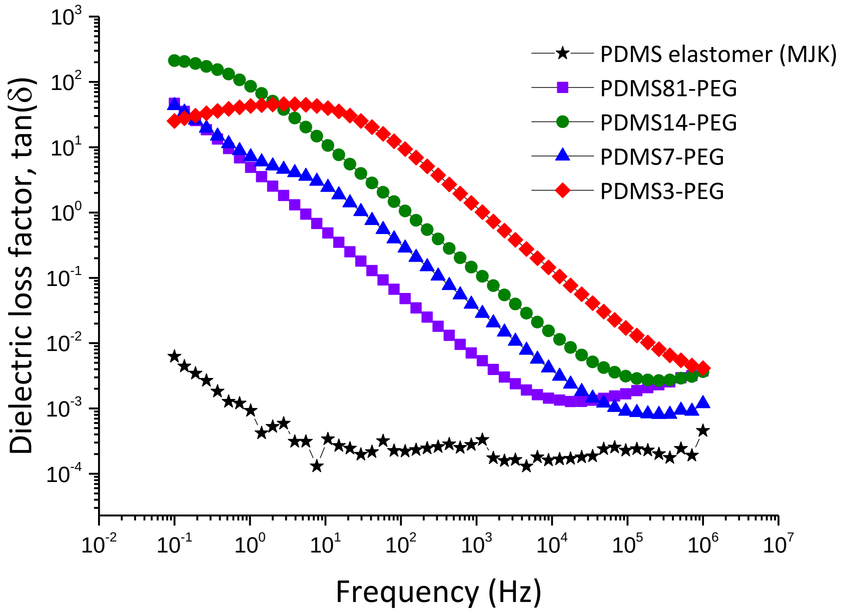
3

1) 1 mm film – rheology & permitttivity

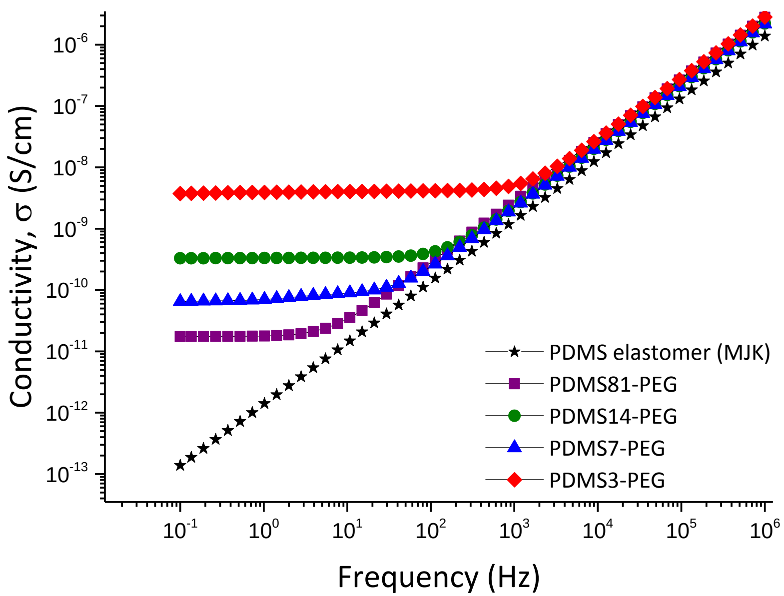
2) 100 µm film – dielectric breakdown strength

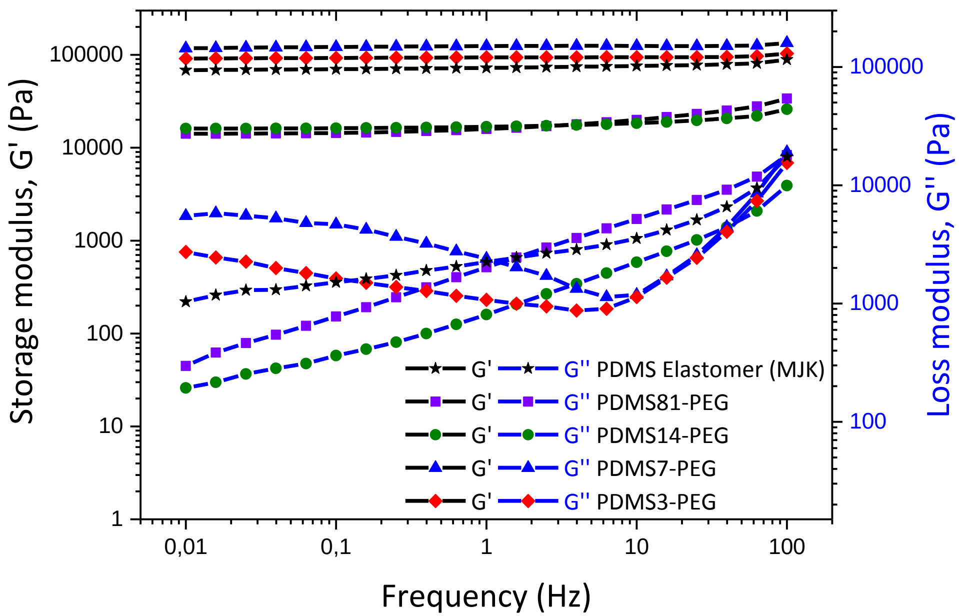
Relative permittivity VS dielectric loss factor (BCP)



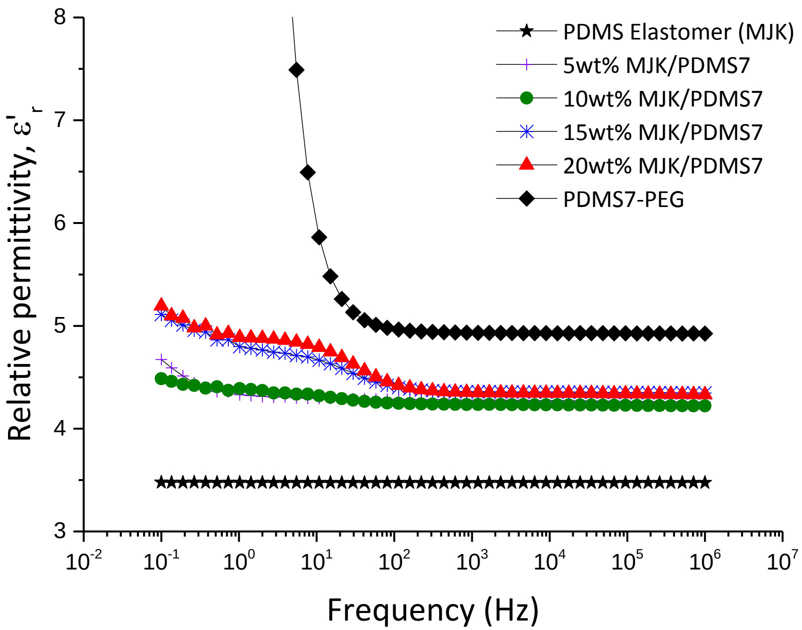


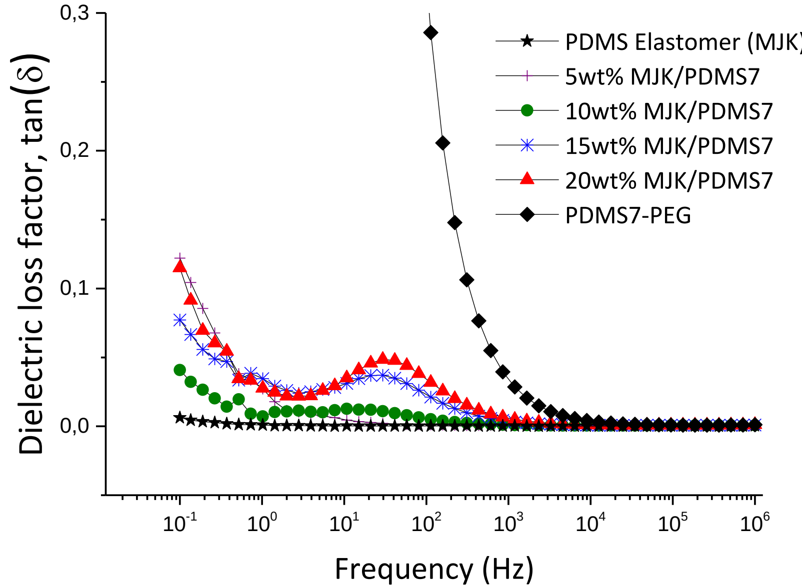
Conductivity and shear modulus (BCP)



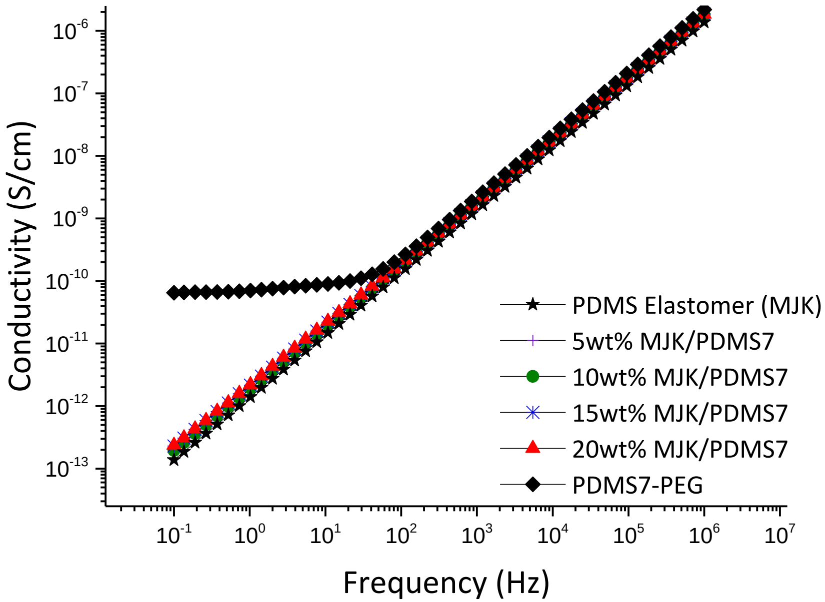


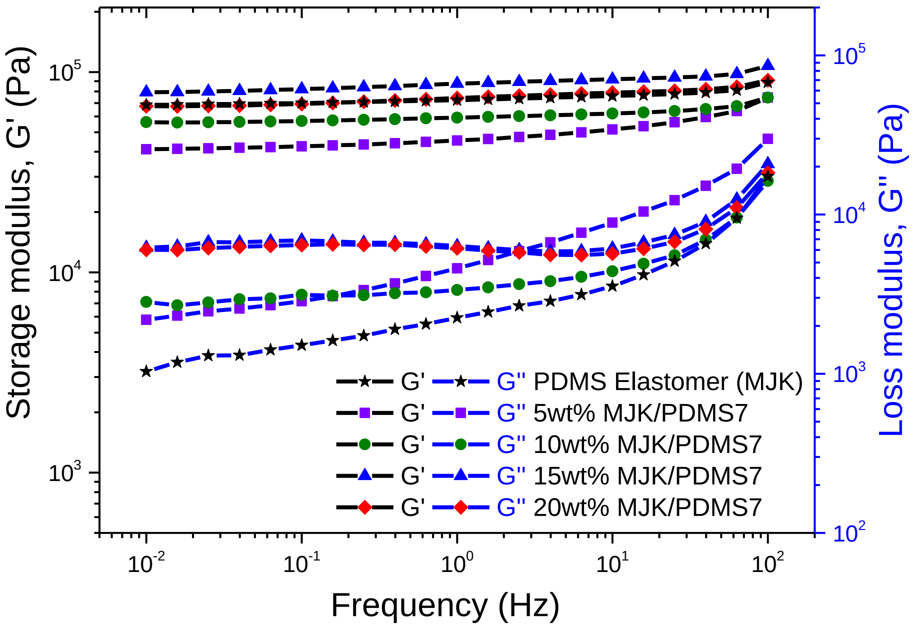
Relative permittivity VS Dielectric loss factor (MJK/PDMS7)



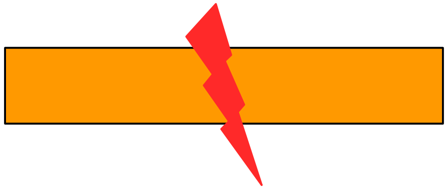


Conductivity & shear modulus (MJK/PDMS7)





Dielectric breakdown (E_{BD}) strength (MJK/PDMS7)



MJK/ PDMS7	Dielectric breakdown E_{BD} (V/µm)	Weibull η-parameter	Weibull β-parameter	R^2 *of linear fit*
MJK	93 ± 7	98	17	0.92
5 wt%	103 ± 4	105	31	0.84
10 wt%	92 ± 3	94	31	0.93
15 wt%	93 ± 8	96	13	0.99
20 wt%	101 ± 5	103	25	0.95

Figure of merit (F_{OM}) - actuator

MJK/PDMS7	Young's modulus, Y* (kPa)	Normalised F_{OM} (DEA)
0 wt% (MJK)	205	6.1
5 wt%	123	17.2
10 wt%	169	9.6
15 wt%	238	8.0
20 wt%	203	11.2

* $Y = 3G'$

F_{OM} (DEA) of Elastosil RT625 (1.86×10^{-24})

$$F_{OM}(DEA) = \frac{3\varepsilon_r\varepsilon_0 {E_{BD}}^2}{Y}$$

Conclusion

- Incorporating conducting PDMS-PEG block copolymer with non-conducting PDMS elastomer:
    - Improve relative permittivity up to **60%** with low loss permittivity and non-conducting.
    - Maintain **low modulus** (obtain soft elastomer).
    - Based on FOM, the actuation improves by **17-fold** compared to reference material (Elastosil RT625).

Thank you & questions

DPP Group

Current members

Previous members